RECIPROCITY CALIBRATION OF MICROPHONES UNDER HIGH AMBIENT PRESSURES

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SUMMARY PAGE

THE PROBLEM

To describe and demonstrate a method of microphone calibration which can be used under high ambient pressures and various gas mixtures.

FINDINGS

It has been shown that the reciprocity calibration procedure is applicable in high pressure environments when the gas mixture and depth are known. Application of the reciprocity principle using a piezoelectric microphone demonstrated that as pressure increased, the sensitivity of the microphone decreased. The change in sensitivity was frequency dependent. Between the frequencies of 3 to 8 kHz, the microphone was essentially stable in sensitivity from 300 to 600 feet.

APPLICATION

This calibration procedure is now being implemented to obtain the sensitivity of microphones under various pressures and gas mixtures. In addition, earphones may now be calibrated in hyperbaric environments, thus allowing for basic evaluation of the hearing mechanism while pressurized.

ADMINISTRATIVE INFORMATION

This investigation was conducted as part of Bureau of Medicine and Surgery Research Work Unit M4306.03-2020DAC5 -- Evaluation of Underwater Communications System for Navy Divers. The present report is No. 5 on this Work Unit. It was approved for publication on 21 July 1971 and designated as Naval Submarine Medical Research Laboratory Report No. 671.

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ABSTRACT

The purpose of this study was to demonstrate a technique for primary calibration of microphones under high ambient pressures and various gas mixtures. The reciprocity calibration technique was chosen for calibrating a piezoelectric microphone to 600 feet in a helium-gas mixture. Corrections for gas mixture and depth changes were applied to the basic reciprocity formula. Using the reciprocity calibration technique with a piezoelectric microphone, it was found that sensitivity decreased at frequencies below 2000 Hertz as pressure increased. At the pressures encountered from 300–600 feet, the sensitivity of the microphone was stable from 3000 to 8000 Hertz. Between the surface and 600 feet depths, there was approximately a 15 to 18 dB loss in sensitivity.

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INTRODUCTION

Recent interest in the problem of high pressure experimentation and habitation has produced a need for the design and analysis of systems specific to the underwater milieu. One such need is the accurate calibration of systems used for measuring psychoacoustic and physioacoustic responses. The specific problem with which this study deals is that of microphone calibration preliminary to the conduct of psychoacoustic experimentation in hearing and speech under high ambient pressures.

A number of methods are available for obtaining absolute calibrations of a microphone. Probably one of the most useful developments for the laboratory worker is that reported by DiMattia and Wiener[1]. They describe a technique for obtaining absolute pressure calibration of a Western Electric Type 640-AA microphone by a reciprocity method. The advantages, as pointed out by the investigators are that: (1) it provides a primary means of calibrating for which no acoustic standards are required, (2) it is applicable over a wide range of frequencies, and (3) the required measurements are easily obtained. The National Bureau of Standards, as well as other organizations who set standards for acoustic equipment, approve of the basic technique as presented by DiMattia and Wiener. Most recently this technique has been recommended by the International Electrotechnical Commission (affiliated to the International Organization for Standardization - ISO), as a precision method for pressure calibration of one-inch standard condenser microphones.[2] In 1955, White demonstrated the use of this technique with a Western Electric 640-AA condenser microphone[3]. This paper describes further application of the reciprocity technique, including its use in helium-rich atmospheres, and presents data obtained in the calibration of a piezoelectric microphone to a simulated depth of 600 feet of sea water (19 ATA).

EQUIPMENT AND PROCEDURE

Adaptation of Standard Reciprocity Calibration Technique

The basic formula for calculating the sensitivity of a microphone according to the reciprocity technique[3] is shown in the upper portion of Figure 1. The diagrams beneath the formula show what measures are needed and how they are obtained. When a sinusodial current (I_q) is applied to a transducer, shown in Figure 1 as the piezoelectric ring (P-E ring), the acoustic output for calibration purposes is a pure tone. In the presence of this pure tone, the voltage output (E_{rp}) of a reciprocity-type microphone (R)* and the output (E_{tp}) of the microphone under test (X) are

A reciprocity-type microphone is a transducer which will emit sound when electrically energized and produce an electrical output when acoustically stimulated.

$$M = \left[\frac{E_{RP}}{E_{TP}} \frac{E_{RT}}{I_T} \cdot \frac{2d\lambda}{\rho c} \right]^{\frac{1}{2}}$$

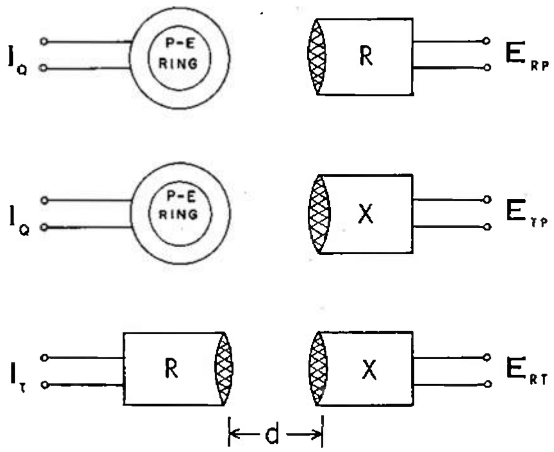

Fig. 1. Basic formula for calculating microphone sensitivity. Diagram shows what measures are needed to calculate microphone sensitivity using the reciprocity method.

obtained. Next, (R) is placed in the exact location of the first source of sound and energized to produce a second sound stimulus. At this time, both the current input (I_t), which is energizing (R) and the output (E_{rt}) of (X) are measured. In each case, the distance between the acoustic transducer and receiver is constant.

The four measurements, E_{rp}, E_{rt}, E_{tp}, and I_t are then used in the reciprocity formula along with several other values which remain constant under laboratory test conditions of standard temperature and pressure. These constants are the distance (d) between the sound source and the various microphones, the wavelength (λ) of the frequency of the stimulus, the density (P) of and velocity (C) of sound within the gas medium between the acoustic transmitter and receiver. When the appropriate figures are applied, the formula yields the absolute sensitivity of the test microphone for the frequency of interest. This sensitivity is commonly expressed as that voltage in dB below one volt which is produced by the microphone when it is exposed to 1 microbar (ubar) of acoustic stimulation. In order to obtain the sensitivity in terms of the frequency response of a microphone, the above calculation is repeated across a number of frequencies.

Figures 2, 3, and 4 show the mathematical derivations which relate the basic formula for microphone sensitivities to the formula used to obtain microphone calibrations under mixed gas and high ambient pressure conditions. Equation 1 in Figure 2 is used to determine the sensitivity of microphones according to the standard reciprocity technique[3]. By substituting terms in Equation 2, we obtain Equation 3, the working formula used for reciprocity calibration. At this point, it is necessary to obtain the current (I_r), which is the current applied to a reversible microphone when that microphone is being used as the sound source. Equation 4 can be used to estimate this current[4] where a known capacitance (C_s) is applied to a voltage (V_s). The resulting equation, Number 5, in Figure 2, is then obtained for determining microphone sensitivity.

The several formulae in Figure 3 show how the large variations in

hyperbaric conditions under study in the present experiment were accounted for. If the volume of the closed-coupler cavity (V_{CC})*, the ratio of specific heats for the gas mixture within the cavity (γ), and the correct capacitance to estimate current (C_S) are all constants for a particular depth, Equation 6 can be rewritten to include the combined constant (q). In Formula (7) the ambient pressure (P_O) equals the number of atmospheric pressures (ATA) multiplied by dynes/cm^2 for one (normal) atmospheric pressure. Note that dynes/cm^2 for 1 ATA is a constant which can be combined with the constant (q) to yield a more convenient constant (k). We now see that Equation 6 can be rewritten as Equation 9 which contains the reciprocal of ambient pressure in ATA multiplied by the single constant (k). In Figure 4, we see this constant (k) in Equation 10. Equation 11 is now obtained using the "READ" values from the General Radio calibrating system[4]. The "READ" values provide the four voltages needed to calculate Equation 10 in Figure 4. The measurements can be taken from a sound level meter when the calibrator unit is set to make the appropriate "READ" settings. Readings are taken on a sound level meter and converted to a voltage if the internal calibration of the sound pressure level meter is known. Using the voltages from the sound level meter, Equation 11 is obtained; this equation was used in the present study to reciprocity calibrate a microphone during the ascent stage of a dive to 19 ATA. For the descending runs, an additional correction to the constant (k) was required due to a change in gas mixture at each depth stop. The specific character which changed to a (γ), the ratio of specific heats for the gas mixture.

Cavity which couples the standard and test microphones as shown in Figure 5.

$$(1) \qquad M_R = \left[\frac{E_{RP}}{E_{TP}} \cdot \frac{E_{RT}}{I_T} \cdot \frac{2\,d\lambda}{\rho\,C}\right]^{\frac{1}{2}}$$

$$(2) \qquad \frac{2\,d\lambda}{\rho C} = \frac{j\omega V_{cc}}{\gamma P_o}$$

$$(3) \qquad M_R = \left[\frac{V_x'}{V_r'} \cdot \frac{V_x}{I_R} \cdot \frac{j\omega V_{cc}}{\gamma P_o}\right]^{\frac{1}{2}}$$

$$(4) \qquad I_R = V_s\, j\omega\, C_s$$

$$(5) \qquad M_R = \left[\frac{V_x'}{V_r'} \cdot \frac{V_x}{V_s} \cdot \frac{V_{cc} \quad j\omega}{\gamma P_o C_s \quad j\omega}\right]^{\frac{1}{2}}$$

Fig. 2. Equations used to obtain the working formula for reciprocity calibration of a microphone.

Vcc, γ and Cs do not change with pressure change

$$(6) \qquad \therefore \quad \frac{V_{cc}}{\gamma C_s P_o} = q\,\frac{1}{P_o}$$

$$(7) \qquad \frac{1}{P_o} = \frac{1}{\text{No. of ATA times dyne/cm}^2 \text{ for 1 ATA}}$$

$$\text{Thus, for 5 ATA}, \ \frac{1}{P_o} = \frac{1}{5 \times \text{dyne/cm}^2 \text{ for 1 ATA}}$$

$$(8) \qquad \text{If we let } K = q\,\frac{1}{(\text{dynes/cm}^2 \text{ for 1 ATA})}$$

Then we have

$$(9) \qquad \frac{V_{cc}}{\gamma C_s P_o} = K\,\frac{1}{(\text{ATA})} \quad \text{for different conditions of ambient pressure.}$$

Fig. 3. Equations used to obtain the constants for different ambient pressures in order to use the reciprocity technique.

$$(5) \qquad M_R = \left[\frac{V_x'}{V_r'} \cdot \frac{V_x}{V_s} \cdot \frac{V_{cc}}{\gamma P_o C_s}\right]^{\frac{1}{2}}$$

$$(10) \qquad M_R = \left[\frac{V_x'}{V_r'} \cdot \frac{V_x}{V_s} \cdot K \frac{1}{ATA}\right]^{\frac{1}{2}}$$

If .001 Volt input to S-L Meter shows 76 dB
and if "READ 1" = 72.2 dB
then, 76 − 72.2 = 3.8
and V_x' = .001 Volts − 3.8 dB = .00064 Volts.
Other Voltages similarily determined.

$$(11) \qquad M_R = \left[\frac{\text{READ 1}}{\text{READ 2}} \cdot \frac{\text{READ 3}}{\text{READ 4}} \cdot \frac{K}{ATA}\right]^{\frac{1}{2}}$$

FORMULA USED IN PRESENT CALIBRATIONS

Fig. 4. Reciprocity calibration equation and its equivalent using the General Radio Reciprocity Calibrator Unit.

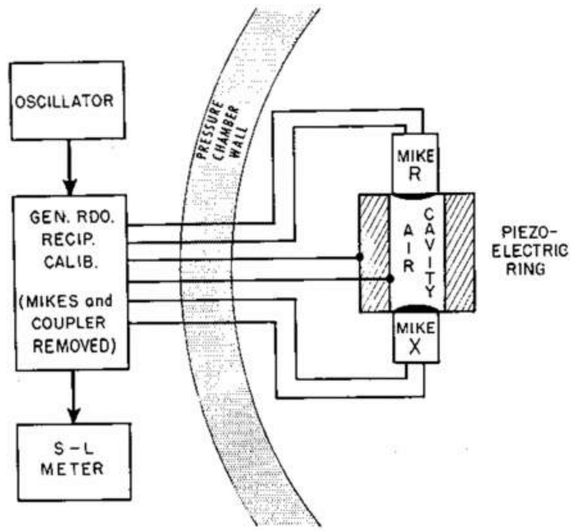

Fig. 5. Schematic diagram of the equipment used inside and outside of the hyperbaric chamber to perform reciprocity calibrations. The pressures inside and outside of the calibration cavity are equivalent.

Figure 5 is a schematic diagram of the equipment used to implement the reciprocity calibration technique under high ambient pressure. A General Radio Microphone Reciprocity Calibrator (Type 1159-B) was located outside of the hyperbaric chamber; the acoustic cavity containing the reciprocity microphone and piezoelectric ring was removed from the calibrator unit and installed in the chamber. The calibrator unit served as a switch to select the proper points for making voltage readings and to energize the transducers within the cavity. A General Radio Beat Frequency Audio Generator (Type 1034-B) fed the calibrator unit and a General Radio Sound Level Meter (Type 1551-B) was used to obtain the voltage readings when the calibrator's switch was set to the various "READ" settings.

For the descent run, the chamber was pressurized to 14 feet with air; pressurization for the remainder of the dive was accomplished using pure helium until a depth equivalent to 600 feet of sea water was reached. Stops were made at 100, 200, 300, 400, and 500 feet in order to obtain a set of voltage readings at each depth. Similar stops were made during the ascent run. Thus, while the gas mixtures varied at each stop during descent, they remained constant during ascent. The microphone under test was a piezoelectric microphone

(General Radio 1560 P-5). This microphone was selected as one type of microphone which should be minimally affected by large changes in ambient pressure. In order to obtain the microphone sensitivity from the voltage readings, a Wang Electronic Computer Model 370 was programmed to perform the necessary calculations. These readings were the needed voltages, obtained from the four switch settings for "READ" selections on the reciprocity calibration unit.

RESULTS AND DISCUSSIONS

Figure 6 graphically presents the results when pressure increased from 0 to 600 feet. The abscissa is frequency and the ordinate describes microphone sensitivity as voltage output in dB below one volt for an acoustic stimulation of one microbar. The parameters are depths in feet submersion into sea water required to produce a particular ambient pressure.

The results show that the overall sensitivity of the microphone tested in this study consistently decreased at frequencies of 2000 Hertz and below as the ambient pressure within the chamber increased. This consistent loss in sensitivity existed at frequencies up to 8000 Hz for depths between surface and 300 feet. At pressures encountered from 300 to 600 feet, the sensitivity of this microphone was stable within the range

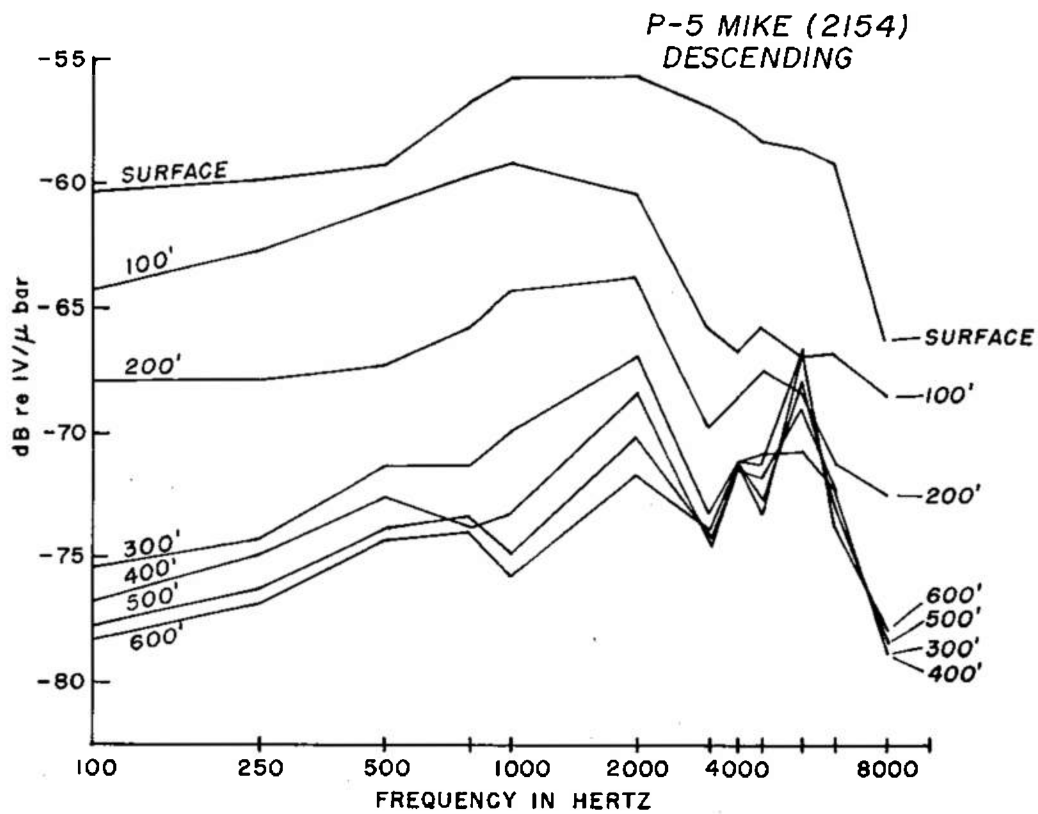

Fig. 6. Microphone sensitivity as determined by the reciprocity technique, for the P-5 microphone at the surface and six depths to 600 feet during descent.

of 3 to 8 kHz. This result is in agreement with White's results obtained with a condenser microphone[2].

Figure 7 presents data for the ascending run from 600 feet to the surface. Changes in sensitivity at the lower frequencies are quite similar to those found during descent, i.e., as ambient pressure decreased sensitivity increased. On the other hand, sensitivity at the higher frequencies did not change noticeably. Note also that the sensitivity across all frequencies was about 5 dB less at the end of the dive than it was prior to compression. However, after a period of seventeen (17) hours, the sensitivity returned to approximately what it had been prior to the experiment. This indicates that recovery at first is only partial, and that complete recovery to the normal pre-pressurized levels probably takes on the order of hours.

SUMMARY

This paper reports the procedure and the results of a reciprocity calibration of a microphone under conditions wherein ambient pressure was varied between one and nineteen times normal atmospheric pressure.

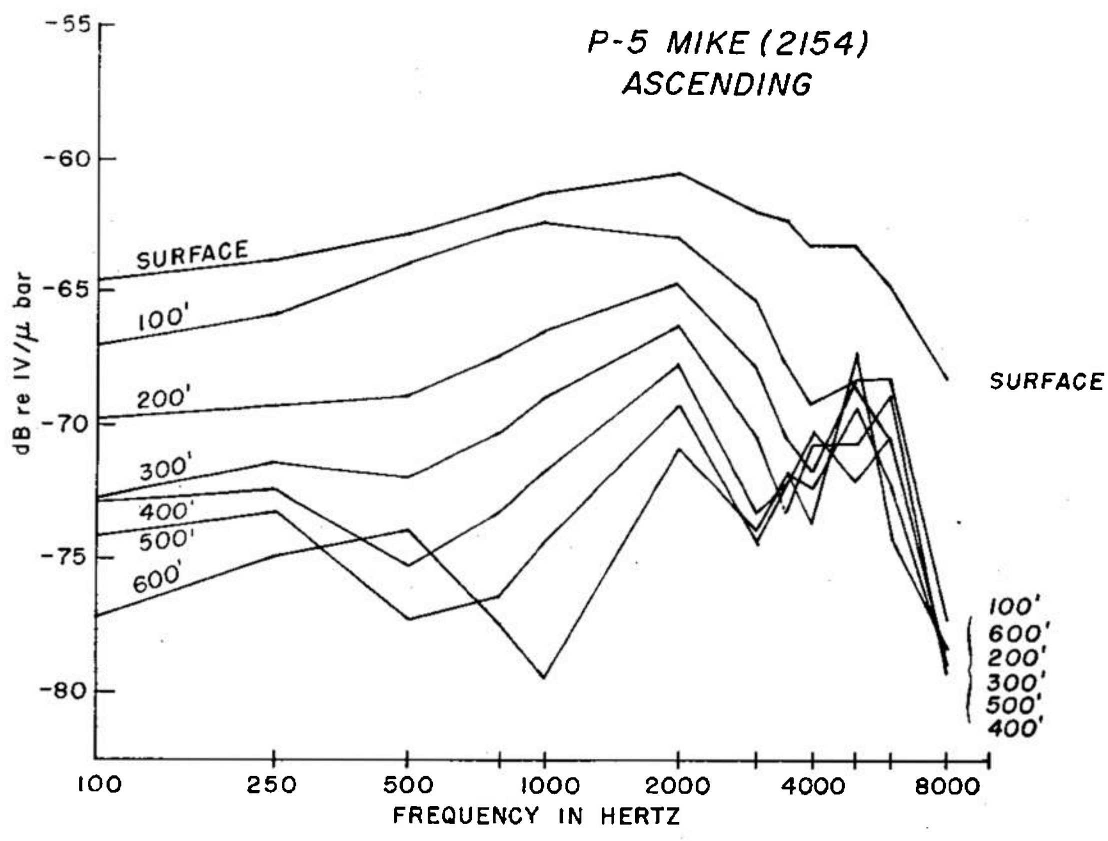

Fig. 7. Microphone sensitivity at six depths and at the surface during ascent.

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13. ABSTRACT

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